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WATER QUALITY CONDITIONS IN GRAND LAKE, SHADOW MOUNTAIN LAKE, LAKE GRANBY

ENVIRONMENTAL PROTECTION AGENCY

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The primary objective of this survey was to develop the water pollution control measures necessary to protect and preserve the recreational and other uses of these lakes. The report discusses physical, chemical, and biological conditions in the lakes and tributaries; nutrient inputs to the lakes from natural runoff; wastewater inflows to the lakes and their nutrient loads; and actions necessary to abate the present pollution and protect the lakes from accelerated eutrophication.

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WATER QUALITY CONDITIONS

in

GRAND LAKE, SHADOW MOUNTAIN LAKE, LAKE GRANBY

EPA

ENVIRONMENTAL PROTECTION AGENCY
Water Quality Office
Pacific Southwest Region
San Francisco, California

December 1970

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I. INTRODUCTION

This survey was carried out under the provisions of Section 1(3) and (5) of Executive Order 11288, "Prevention, Control and Abatement of Water Pollution by Federal Activities," which states:

> "Pollution caused by all other operations of the Federal Government, such as water resources projects and operations under Federal loans, grants, or contracts, shall be reduced to the lowest level practicable," and "The Secretary of the Interior shall, in administering the Federal Water Pollution Control Act, as amended, provide technical advice and assistance to the heads of other departments, agencies, and establishments in connection with their duties and responsibilities under this order," respectively.

The Superintendent, Rocky Mountain National Park, Midwest Region, National Park Service, in a letter dated April 19, 1968, requested the assistance of the Federal Water Pollution Control Administration to determine the measures necessary to prevent the pollution of Lake Granby, Shadow Mountain Lake and Grand Lake (Figure 1). Shadow Mountain Lake and Lake Granby are within the Shadow Mountain National Recreation Area which is part of his jurisdiction. However, the survey included all three lakes since their water quality is interdependent.

In response to this request, the Colorado River-Bonneville Basins Office, Federal Water Pollution Control Administration, conducted a preliminary survey from August 28-September 6, 1969, of Shadow Mountain Lake, Grand Lake, Lake Granby and their tributaries.

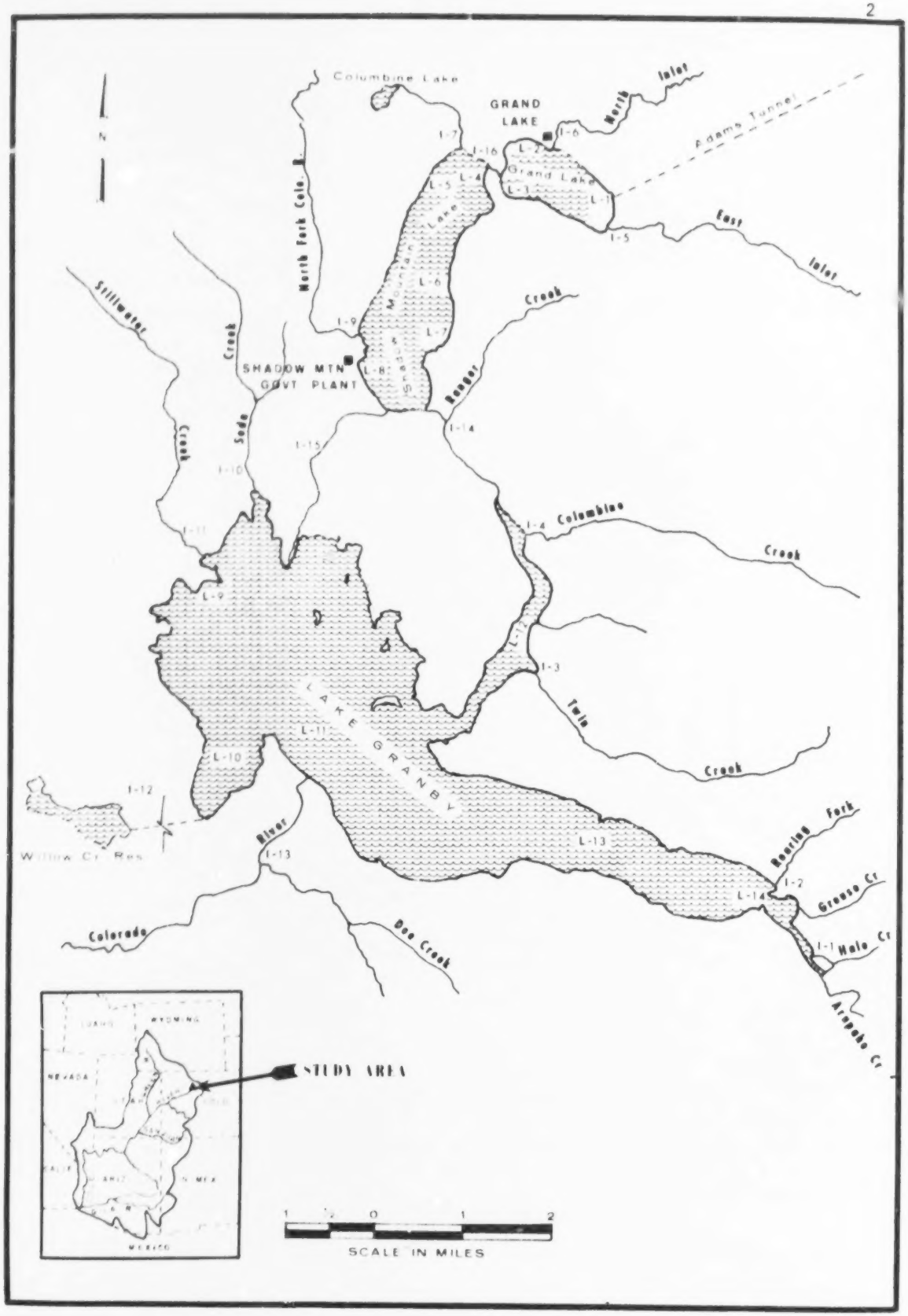

Figure 1. Grand Lake, Shadow Mountain Lake, Lake Granby Study Area

Acknowledgments

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We acknowledge the assistance provided by personnel of the National Park Service and the Bureau of Reclamation during this survey.

II. HISTORY AND STATEMENT OF THE PROBLEM

The establishment of the Rocky Mountain National Park in 1915 began the development of this important recreational area. The proximity of Grand Lake, which is the largest natural body of water in Colorado, to the National Park made the region around the lake a popular summer home and resort area. Then, in the late 1940's, the U. S. Bureau of Reclamation, as part of the Colorado-Big Thompson Project, constructed Granby Dam and Shadow Mountain Dam forming Lake Granby and Shadow Mountain Lake respectively. The primary purpose for the construction of these dams was to supply irrigation water for eastern Colorado. Today, the water of these lakes serve myriad purposes on both sides of the Rockies such as power production, public water supplies, fishing, boating, and body contact sports. The three lakes and the surrounding area on the western slope have become one of the most popular recreational spots in Colorado and are visited by tens of thousands of people annually.

The sewage treatment systems that serve these thousands of visitors are primarily pit or vault toilets or septic tanks. There are two collection and treatment systems in the area. The Shadow Mountain Government Camp is sewered and treatment is provided by septic tanks, subsurface contact filters and chlorination. This system was constructed in 1939 and enlarged in 1949. The effluent is discharged directly into Shadow Mountain Lake. Part of the Community of Grand Lake is served by a trickling filter plant built in 1951 which discharges to Shadow Mountain Lake. The population served by this plant varies from approximately 150 people during the winter to 4,000 people during the summer (recreation

season). The remainder of the community is served by individual disposal systems.

Partially treated wastewater has been discharged into Shadow Mountain Lake for more than 20 years, but evidence of pollution has not become apparent until recent years. On October 2, 1967, the Public Health Service consultant to the National Park Service surveyed Shadow Mountain Lake at the request of the National Park Service. This survey resulted from the complaints of local residents and businessmen located on the west side of Shadow Mountain Lake. The nature of the complaints were varied but were along the following general lines:

1. Large accumulations of persistent foam.
2. Algae formations along the shoreline and on boats anchored in docking areas.
3. Floating solids and sludge deposits.
4. Turbidity caused by sludge in water. (This was subsequently identified as algae bloom.)

The observed conditions in Shadow Mountain Lake were:

1. Light to moderate algae growth along the west shoreline from the Headquarters area to Grand Lake.
2. Some small accumulations of persistent foam at various points along the shoreline.
3. Moderate algae bloom along the west shoreline.
4. Generally heavy turbidity in the western portions of the Lake apparently caused by sludge accumulations.

From these observations, the Public Health Service consultant in a letter to the Superintendent, Rocky Mountain National Park, dated October 5,

1967, stated that, "Results of the investigation, while not conclusive due to lack of quantitative evidence, do indicate the presence of domestic pollution of sufficient strength to create public health hazards."

In May 1968, the Colorado Water Pollution Control Commission adopted general standards applicable to all waters of the state. In addition, the three lakes have been classified as suitable for potable water supplies (Class A) and for cold water fisheries (Class B_1). The specific standards for these uses include dissolved oxygen not less than 6.0 mg/l, pH between 6.5 and 8.5, and temperature not to exceed 70°F (21.1°C). The complete water quality standards for these waters are reproduced in Appendix B.

The Secretary of the Interior in approving the Colorado Water Quality Standards requested that the three lakes also be classified for body contact sports (B_3) based upon the existing recreational uses. The Commission has conducted some sampling of the lakes over the past two years to obtain background data for adding this classification. The addition of a B_3 classification would make the bacteriological criteria for the lakes more stringent. The specific standards applicable to recreational waters classified for body contact sports are also reproduced in Appendix B.

The increasing recreational use of this area, the occurrence of nuisance algae growths, and the apparent pollution of these lakes brought about the National Park Service request to the Federal Water Pollution Control Administration for assistance in defining the effects of wastewater on these lakes and in developing the necessary corrective measures.

III. OBJECTIVES

The primary objective of this survey was to develop the water pollution control measures necessary to protect and preserve the recreational and other uses of these lakes. To accomplish this, the following specific objectives were pursued:

1. To determine the existing physical, chemical, and biological conditions in the lakes and tributaries.
2. To determine the nutrient inputs to the lakes from natural runoff.
3. To locate and identify the wastewater inflows to the lakes and measure their nutrient loads.
4. To evaluate the pollution potential from increased recreational use in the surrounding area.
5. To recommend the actions necessary to abate the present pollution and protect the lakes from accelerated eutrophication.

IV. SUMMARY AND CONCLUSIONS

1. The laboratory analyses of samples collected from Grand Lake, Shadow Mountain Lake, and Lake Granby show that the inorganic nitrogen concentrations were uniform throughout the lakes and averaged 0.107 mgN/l over the survey period. This concentration is approximately one-third of that considered necessary to initiate an algae bloom (0.30 mgN/l). The orthophosphate concentration in the three lakes averaged 0.0255 mgP/l and ranged from 0.0084 mgP/l in Grand Lake to 0.0526 mgP/l in Shadow Mountain Lake. This average concentration greatly exceeds the minimum level of orthophosphate considered by authorities in the field as necessary to sustain an algae "bloom" (0.010 mgP/l). In addition, the orthophosphate concentration at the bottom of Lake Granby ranged from two to thirteen times greater than surface concentrations indicating the possibility that anaerobic respiration may take place in the benthic regions.
2. The average inorganic nitrogen, orthophosphate, and total soluble phosphorus concentrations in the natural runoff from the surrounding watershed were 0.07 mgN/l, 0.007 mgP/l, and 0.064 mgP/l respectively. The inorganic nitrogen and orthophosphate concentrations are much lower than the suggested limits of 0.30 mgN/l, and 0.010 mgP/l respectively, but the total soluble phosphorus concentrations exceeded the suggested limit of 0.05 mgP/l.
3. The domestic wastewater sources in the three lakes area are the Grand Lake wastewater treatment facility, the Shadow Mountain Government Camp wastewater treatment facility and the numerous individual subsurface

disposal systems serving homes and businesses along the shores. Effluents from the two treatment facilities are the largest point sources of nutrients entering the lakes. Analyses of the Grand Lake wastewater treatment facility effluent, the largest wastewater discharge, showed average inorganic nitrogen, orthophosphate and total soluble phosphorus concentrations of 13.43 mgN/l, 5.21 mgP/l and 6.14 mgP/l respectively. In terms of total load, this plant provided only 0.28 percent of the total inflow to the lakes but supplies 36.0 percent of the inorganic nitrogen, 68 percent of the orthophosphate and 21.5 percent of total soluble phosphorus loads to the lakes during this survey. Therefore, advanced waste treatment methods including at least 80 percent orthophosphate removal, wastewater export, or total containment of effluents in ponds will be required to preserve the present water quality and reduce the nutrient concentrations in the lakes.

4. The concentration of orthophosphate, the phosphorus form most readily available for biological growth, is sufficiently high that any one or all three of the lakes could sustain nuisance algae blooms. Wastewaters contributed the major portion of orthophosphate to the lakes with the Grand Lake wastewater treatment facility alone contributing 68 percent of the measured orthophosphate load. It is estimated, based upon data obtained in this survey, that the combined wastewater flows contribute more than 80 percent of the annual orthophosphate load. The low inorganic nitrogen concentrations existing in the lakes and inflows and the presence of Aphanizomenon flos-aquae and Anabaena sp., both atmospheric nitrogen fixers, indicate that the lake waters are nitrogen deficient and the phytoplankton growth is nitrogen limited.

5. Temperature measurements showed that Lake Granby and Grand Lake had thermally stratified layers although thermoclines, as defined in the glossary, were not in evidence. Shadow Mountain Lake was generally isothermal as expected because of its shallow depth and the effects of mixing.

6. The dissolved oxygen concentration in the near surface waters of all three lakes exceeded the 6.0 mg/l standard for cold water fisheries at all stations except for Station L-5 on Shadow Mountain Lake. The dissolved oxygen concentration at this sampling station, which is located near the west shore of the Lake between two marinas, was 5.6 and 5.2 mg/l on September 1 and 3, 1969, respectively. The dissolved oxygen concentrations were 3.0 mg/l or greater throughout the depths of all three lakes. Grand Lake and Shadow Mountain Lake had dissolved oxygen profiles approximating an orthograde pattern, but the profile in Lake Granby approached a clinograde pattern with concentrations of less than 6.0 mg/l in the hypolimnion. This oxygen deficit is caused by a natural deposition of oxidizable organic material in Lake Granby during spring runoff. Because much of the organic material is probably either suspended in natural runoff or photosynthesized in the lakes, the depletion of dissolved oxygen in the hypolimnion of Lake Granby is not readily correctable and will worsen with time. There is no data available which reflects the effects of this organic material upon the dissolved oxygen concentration of Lake Granby during other periods of the year. Since this lake is stocked regularly with game fish, the combined effects of the organic matter and ice cover on the dissolved oxygen concentrations and game fishery should be investigated.

7. The Secchi Disk transparency measurements indicate that the euphotic zone extended through the epilimnion into or below the zone of greatest temperature change in the three lakes. In addition, the Sedgwick-Rafter analyses of plankton samples did not show any variation between total plankton counts with depth. This indicates that the entire epilimnion receives sufficient light energy to support photosynthesis. Total phytoplankton analyses by the Sedgwick-Rafter method gave maximum counts of 527 organisms/ml in Grand Lake, 272 organisms/ml in Shadow Mountain Lake, and 221 organisms/ml in Lake Granby. Eight of sixteen phytoplankton samples had less than 200 organisms/ml which indicate low to moderate biological productivity in all the lakes. Numerically, Dinobryon sp., a yellow-green algae which causes taste and odor problems when present in high concentrations, was the most abundant organism. The blue-green algae Aphanizomenon flos-aquae which is capable of fixing atmospheric nitrogen was discernable in the surface waters of all three lakes and was the predominant organism recovered in net plankton samples.
8. The biological results showed no evidence of an algal "bloom" during this survey. On the basis of dissolved oxygen and nutrient concentrations, depth of the euphotic zone, and plankton populations, none of the three lakes could be considered eutrophic. The productivity of Granby and Grand Lakes is such that their classifications are between oligotrophic and mesotrophic. Shadow Mountain Lake was the most productive and could be classed as a mesotrophic lake.
9. The existing water quality of the three lakes is equal to or better than the standards established for the classified uses of the three lakes except that the dissolved oxygen concentrations in the hypolimnion of Lake

Granby were less than the established standards of 6.0 mg/l. It is possible that natural sources of organic material are the major cause of the depressed dissolved oxygen. The limited scope and duration of the study, however, did not permit a complete evaluation of this situation, and further study is indicated to provide a basis for remedial action.

V. RECOMMENDATIONS

In order to protect and/or enhance water quality and water uses of Grand Lake, Shadow Mountain Lake, and Lake Granby, it is recommended:

1. That the classification, B_3, Body Contact Recreation, be added to the water uses established for the three lakes.
2. That the Colorado Water Pollution Control Commission establish water quality standards for the three lakes and their tributaries containing nutrient criteria and required waste treatment and other control measures which will not only prevent further enrichment of these waters but enhance their quality.
3. That immediate action be taken to control and treat all wastewaters in the three-lakes watershed by either, (a) total containment, (b) advanced waste treatment which will limit the flow weighted inorganic nitrogen, orthophosphate and total phosphorus concentrations of the combined natural and wastewater inflows to the lakes of less than 0.30 mgN/1, 0.010 mgP/1 and 0.050 mgP/1, respectively, or (c) secondary waste treatment with discharge to the Colorado River below Lake Granby.
4. That the Federal agencies immediately implement recommendation number 3 in order to control the contribution to water pollution from their activities or facilities. In conjunction with this, the Federal agencies must cooperate with and assist the local government in the development and implementation of an adequate regional wastewater treatment system.

5. That a comprehensive plan for water pollution control and quality management be developed for the three-lakes watershed. This plan should include a regional wastewater collection, treatment and disposal system to be fully implemented no later than 1975. The plan must also provide the controls necessary to insure that future development will not degrade the water quality of the three lakes.
6. That the water quality of the lakes, natural inflow and waste sources be monitored periodically to determine seasonal changes in nutrient loads, and to evaluate the effectiveness of any improvements or additions made to the present wastewater treatment facilities. The National Park Service, the Bureau of Reclamation, and the State of Colorado should make arrangements to accomplish this monitoring.

VI. DESCRIPTION OF STUDY AREA

Lake Granby and Shadow Mountain Lake are manmade reservoirs linked by channels to Grand Lake, the largest natural body of water in Colorado. The three lakes are located on the headwaters of the Colorado River (Figure 1).

Grand Lake is a glacial lake naturally impounded by the terminal moraines of the glaciers that created the present valleys of the North Inlet and East Inlet (5). It has steep sides along the northern and eastern shores and is shallow along the southern and western shores formed by the terminal moraines. The lake has a maximum depth of greater than 200 feet (69.9M), a surface area of 504 acres (2 sq.Km), and a normal water surface elevation of 8367 feet (2548M) (11).

Shadow Mountain Lake is impounded by a low dam across the Colorado River below Grand Lake and provides passage and flow regulation for water being diverted to the eastern slope of the Colorado Rockies through the Alva B. Adams Tunnel. This lake lies wholly within the Shadow Mountain National Recreation Area with the eastern shore forming the boundary for the Rocky Mountain National Park. Most of the land along the west and north shores is privately owned and has been developed as summer home sites, resorts and marinas. Shadow Mountain Lake has a maximum capacity of 18,359 acre-feet ($22.6 \times 10^6 M^3$), an active storage of 1850 acre-feet ($2.3 \times 10^6 M^3$), and a maximum surface area of 1852 acres (7.5 sq.Km.). The average and maximum depths are 10 (3M.) and 37 feet (11.3M.), respectively. The maximum water surface elevation is 8367 feet (2548M) above sea level and the maximum drawdown head is 20 feet (6.1M.). A check structure is

located between Shadow Mountain and Grand Lake so the water surface elevation of Shadow Mountain Lake can be lowered without affecting Grand Lake. However, the usual operating practice is to maintain Shadow Mountain Lake at the same elevation as Grand Lake. (11)

Lake Granby, which stores the majority of the water supply for the Colorado-Big Thompson Project, is formed by Granby Dam and four dikes which impound the waters of the Colorado River and the water pumped from Willow Creek Reservoir. This lake lies wholly within the Shadow Mountain National Recreation Area and forms part of the boundary for the Rocky Mountain National Park. Most of the establishments along the shores of Lake Granby are boat launching areas, parks, and campgrounds for the summer tourists. Lake Granby has a maximum capacity of 540,000 acre-feet ($666 \times 10^6 M^3$), and an active storage of 466,000 acre-feet ($575 \times 10^6 M^3$). The lake covers a surface area of 7,260 acres (29.4 sq.Km.) at the maximum water surface elevation of 8,280 feet (2521M) above mean sea-level. The average and maximum depths are 74 (22.5M) and 200 feet (60.9M), respectively. The outlet at the face of Granby Dam is set between elevations 8150 (2481.7M) and 8190 feet (2493.8M), but active storage is considered to extend downward to elevation 8186 feet (2492.6M) providing a maximum drawdown head of 94 feet (28.6M) (11).

The annual operation summary and average monthly summaries for the Colorado-Big Thompson Project are shown in Tables I and II respectively. Analysis of the average monthly inflows and outflows, which are plotted on Figure 2, shows two general flow patterns through the lakes. Sixty percent of the average annual inflow generally occurs in May and June. The average diversion through the Adams Tunnel during these same months was about 24,900 acre-feet ($30.7 \times 10^6 M^3$). The basic flow pattern is from Grand Lake and

TABLE I Annual Operations Summary, Western Slope Features of the Colorado-Big Thompson Project 1953-1968

Year	Total Inflow AF[1/]	End of Year Storage: Lake Granby AF[1/]	End of Year Storage: Shadow Mtn. Lake AF[1/]	Pumped to Shadow Mtn. Lake AF[1/]	Outflows: Adams Tunnel AF[1/]	Outflows: Colorado River AF[1/]	Seepage AF[1/]
1953	200,756	427,335	18,149	164,919	205,247	25,767	6,701
1954	147,918	230,050	18,111	278,644	320,794	25,738	3,446
1955	204,082	168,436	18,111	195,386	237,108	25,712	854
1956	266,737	188,398	17,780	188,783	220,735	25,745	726
1957	446,151	418,061	17,542	161,792	188,541	25,573	2,594
1958	243,797	387,444	17,725	228,916	243,416	25,218	5,588
1959	251,832	352,567	17,578	214,261	257,920	25,660	3,906
1960	287,785	365,772	17,707	207,912	244,871	25,683	3,895
1961	297,763	460,852	17,854	130,025	173,562	24,426	3,756
1962	317,878	437,977	17,872	173,072	237,105	98,931	5,419
1963	193,674	306,412	17,872	239,452	297,426	24,617	3,178
1964	221,953	190,117	17,670	253,022	310,074	27,074	1,302
1965	375,316	346,635	17,651	141,021	188,371	28,846	1,600
1966	166,014	214,714	17,633	221,362	271,091	24,971	1,892
1967	283,981	236,878	17,651	196,016	232,666	28,064	1,069
1968	248,630	259,640	17,578	167,418	196,213	28,673	1,075
AVG.	259,642	311,956	17,780	197,625	239,032	30,669	2,938

1/ To convert to M^3 multiply by 1233.5.

TABLE II Average Monthly Summaries, Western Slope Features of the Colorado-Big Thompson Project 1953-1968

Month	Total Inflow	End of Month Storage		Pumped to Shadow Mtn. Lake	Outflows		
		Lake Granby	Shadow Mtn. Lake		Adams Tunnel	Colorado River	Seepage
	AF[1/]	AF[1/]	AF[1/]	AF[1/]	AF[1/]	AF[1/]	AF[1/]
Jan.	3,725	295,782	17,827	24,275	25,070	1,212	258
Feb.	3,206	282,662	17,819	21,838	22,512	1,110	213
Mar.	3,700	252,796	17,869	23,312	24,304	1,614	205
Apr.	14,052	253,582	17,465	13,240	17,015	2,614	178
May	64,574	297,200	17,451	3,838	16,072	4,933	171
June	97,246	380,158	17,527	1,386	8,781	5,274	199
July	36,848	392,470	17,673	11,152	17,558	6,564	276
Aug.	12,643	381,529	17,706	17,346	20,809	2,432	312
Sept.	7,815	368,546	17,715	17,834	19,078	1,233	300
Oct.	6,655	352,906	17,689	18,150	20,719	1,288	300
Nov.	5,093	334,141	17,739	21,247	22,332	1,187	274
Dec.	4,085	311,956	17,780	24,007	24,782	1,208	252

1/ To convert to M^3 multiply by 1233.5.

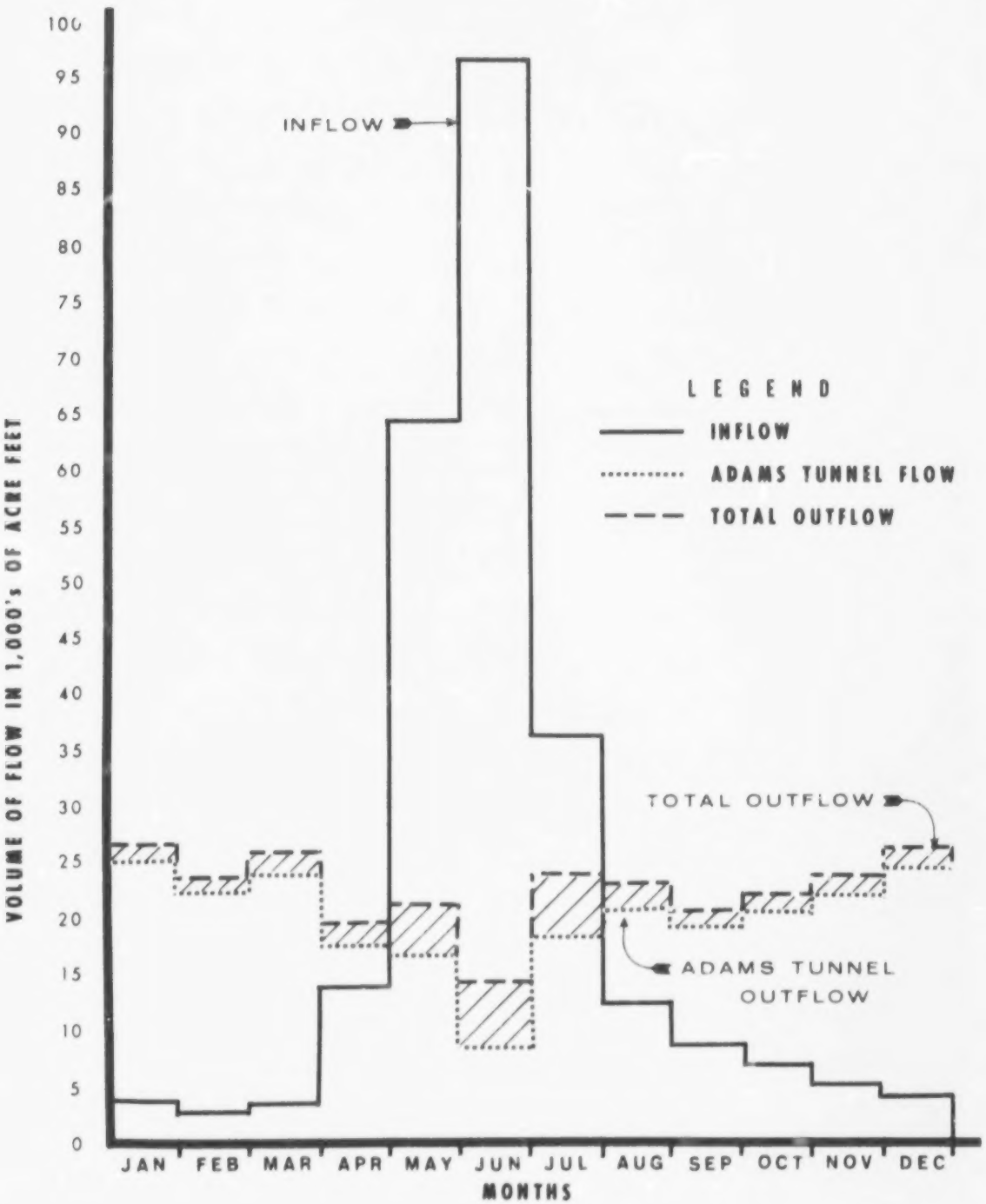

Figure 2. Average Monthly Inflow & Outflow, Grand Lake, Shadow Mountain Lake & Lake Granby

Shadow Mountain Lake into Lake Granby during this time.

During the period August through April, the flow through the Adams Tunnel greatly exceeds the areal runoff into the lakes and water must be pumped from Lake Granby for diversion to the eastern slope. During this time, the flow pattern can generally be described as being from Lake Granby through Shadow Mountain Lake and Grand Lake into the Adams Tunnel.

To protect the existing fisheries in the Colorado River, the U. S. Bureau of Reclamation maintains minimum flow below both Shadow Mountain and Granby Dams. The minimum releases from Shadow Mountain Dam are 25 cfs (.7 M^3/Sec) during October through April and 50 cfs (1.4 M^3/Sec) during May through September. The minimum releases from Granby Dam are 20 cfs (.6M^3/Sec) during September through April, 75 cfs (2.1 M^3/Sec) during May through July, and 40 cfs (1.1M^3/Sec) during August.

VII. METHODS OF SURVEY

The survey of existing water quality conditions was accomplished in two phases. The physical and chemical survey was conducted from August 28, to September 3, and the biological survey on September 5 and 6, 1969. During the physical and chemical survey, 14 stations on the three lakes and 12 stations on tributaries and waste sources were sampled to establish the existing physical and chemical quality parameters (Figure 1).

The Grand Lake wastewater treatment facility effluent (I-16) and Shadow Mountain Reservoir near the channel to Grand Lake (L-4) were sampled daily and the Grand Lake Stations (L-1, L-2, L-3) were sampled every other day. All other stations were sampled as shown in Table III. Water quality samples and measurements were taken at mid-depth from all inflow and outflows. At the lake stations, water quality samples and measurements were taken at the surface and the bottom except where the total depth was 20 feet (6.1M) or less. In the latter cases, water quality samples and measurements were taken at mid-depth.

Temperature, conductivity, dissolved oxygen concentration and pH were measured at each point where a sample was collected for nutrient analyses. The samples were analyzed using standard procedures:

1. Nitrate - soluble inorganic nitrogen.
2. Ammonia - evidence of organic pollution.
3. Total Kjeldahl nitrogen - total organic nitrogen.
4. Orthophosphates - Phosphorus available for instant biological use.
5. Total soluble phosphates - total phosphorus available for biological use.

These analyses were performed by the Services Branch, Colorado River-Bonneville Basins Office, Federal Water Pollution Control Administration.

During the biological survey, nine lake stations, three on each lake, were sampled to establish the biological quality of the lakes. During the biological sampling, light penetration was measured using the Secchi Disk; water samples were collected for phytoplankton analysis; and net drags or vertical hauls were made at selected stations for a qualitative phytoplankton analysis. In addition, the temperature and dissolved oxygen concentrations at various depths were measured in all three lakes. The biological analyses were performed by personnel of the Services Branch, California-Nevada Basins Office, Federal Water Pollution Control Administration.

The survey areas and sampling station locations are depicted in Figure 1. The location, dates and types of sampling for each station are listed in Table III.

TABLE III Station Location, Dates and Type of Samples Collected, 1969

STATION		DATES AND TYPE OF SAMPLES COLLECTED		
No.	Location	Physical	Chemical	Biological
I-1	Arapaho Creek at Bridge	Aug. 28	Aug. 28	
I-2	Roaring Fork at Mount	Aug. 28	Aug. 28	
I-3	Twin Creek at Mouth	Aug. 28	Aug. 28	
I-4	Columbine Creek at Mouth	Aug. 28	Aug. 28	
I-5	East Inlet at Mouth	Aug. 28	Aug. 28	
I-6	North Inlet at Grand Ave. Bridge	Aug. 28 Sept. 2	Aug. 28 Sept. 2	
I-7	Little Columbine Creek at Gaging Station	Aug. 28	Aug. 28	
I-9	Colorado River at Gaging Station near Mouth	Aug. 28 Sept. 2	Aug. 28 Sept. 2	
I-10	Soda Creek at Hwy 34 Crossing	Aug. 28	Aug. 28	
I-11	Stillwater Creek at Gaging Station	Aug. 28 Sept. 2	Aug. 28 Sept. 2	
I-13	Colorado River below Lake Granby at Bridge	Aug. 28	Aug. 28	
I-16[1/]	Grand Lake Wastewater Treatment Facility Outlet	Aug. 28 through Sept. 3	Aug. 28 through Sept. 3	
L-1	Grand Lake about 100 yards east of west portal	Aug. 28&30 Sept. 1&3	Aug. 28&30 Sept. 1&3	Sept. 6
L-2	Grand Lake between the two marinas on Grand Beach	Aug. 28&30 Sept. 1&3	Aug. 28&30 Sept. 1&3	Sept. 6
L-3	Grand Lake about 50 yards out from house with slide	Aug. 28&30 Sept. 1&3	Aug. 28&30 Sept. 1&3	Sept. 6

1/ Bacteriological Quality determined by Colorado State Health Department (2).

TABLE III (Continued) Station Location, Dates and Type of Samples Collected 1969

STATION		DATES AND TYPE OF SAMPLES COLLECTED		
No.	Location	Physical	Chemical	Biological
L-4	Shadow Mountain Lake between entrance to Grand Lake channel and marina.	Aug. 28 through Sept. 3	Aug. 28 through Sept. 3	Sept. 5
L-5	Shadow Mountain Lake between Lake Kove and Shadow Mountain Marina.	Aug. 29 Sept. 1&3	Aug. 29 Sept. 1&3	
L-6[1/]	Shadow Mountain Lake at center of lake.	Aug. 29 Sept. 2	Aug. 29 Sept. 2	Sept. 5
L-7	Shadow Mountain Lake about 50 yards from east shore.	Aug. 29 Sept. 2	Aug. 29 Sept. 2	
L-8[1/]	Shadow Mountain Lake at National Park Service boat dock.	Aug. 29&30	Aug. 29&30	Sept. 5
L-9	Lake Granby 100 yards out from Stillwater Campground boat launch.	Aug. 29 Sept. 2	Aug. 29 Sept. 2	
L-10	Lake Granby in Rainbow Bay midway between boat ramp and Lochleven Cove.	Aug. 29 Sept. 2	Aug. 29 Sept. 2	
L-11	Lake Granby at Center	Aug. 29 Sept. 2	Aug. 29 Sept. 2	Sept. 6
L-12[1/]	Lake Granby 300 yards north of Twin Creek in Grand Bay.	Aug. 29 Sept. 2	Aug. 29 Sept. 2	Sept. 6
L-13[1/]	Lake Granby about 400 yards south of Twin Pines Point.	Aug. 29	Aug. 29	Sept. 6
L-14[1/]	Lake Granby in the middle of Arapaho Bay.	Aug. 29 Sept. 2	Aug. 29 Sept. 2	

1/ Bacteriological Quality determined by Colorado State Health Department (2).

V. DISCUSSION OF FINDINGS

The intent of this survey was to evaluate the existing water quality conditions, define the effects of wastewaters, and recommend remedial measures to protect the lakes. To accomplish this, the analytical results of this survey were compared with established water quality standards where applicable and with the recommended limits for those parameters for which standards have not been set.

With the exception of nutrient concentrations, the Colorado Water Quality Standards established limits for all the physical and chemical parameters measured during this survey. The limiting values for the former, which are discussed below, are based on previous work reported in the literature.

Several investigators (3,6) have concluded that concentrations of inorganic nitrogen exceeding 0.30 mgN/l in lakes could be expected to produce nuisance algae blooms, although it has also been shown that many blue-green algae species, particularly Anabaena and Aphanizomenon, can fix sufficient amounts of atmospheric nitrogen to sustain high productivity. For evaluation of the data obtained in this survey, an inorganic nitrogen limit of 0.30 mgN/l in Lakes appears reasonable. The limiting value is also 0.30 mgN/l for all tributary streams sampled.

Although much has been written about the effects of phosphorus upon algae growth, the level of phosphorus necessary to sustain a nuisance algae growth has yet to be quantified. From the results of previous investigations (6,7,8), it appears that the orthophosphate concentration in a lake must be limited to 0.01 mgP/l to prevent algae blooms. With respect to the

concentrations in streams, Mackenthun (7) has recommended that the total soluble phosphorus concentrations be limited to 0.05 mgP/l. However, this limit is considered applicable only during low-flow conditions and the average annual orthophosphate concentration in the stream should not exceed the limit proposed earlier for the lakes.

EXISTING WATER QUALITY IN THE LAKES

Individual results of the nutrient samples collected from the lakes for analysis are shown in Table A-1 in the Appendix. These data have been summarized and the high, low and average orthophosphate and total soluble phosphate and inorganic nitrogen concentrations are shown in Table IV. Comparing the summary of data with the nutrient criteria discussed above, all three lakes are nitrogen deficient but contain sufficient phosphorus concentrations to support algae "blooms." In such circumstances, only those algae species capable of providing their own nitrogen by atmospheric nitrogen fixation can cause "blooms."

The nutrient levels in Grand Lake (Station L-1, L-2, L-3) and Shadow Mountain Lake (Station L-4 through L-8) did not vary appreciably with depth. The only exception is Station L-8 where the inorganic nitrogen, orthophosphate and total soluble phosphate concentrations measured on August 29, 1969, were approximately four times the lake averages shown in Table IV. One possible explanation is that the effluent from the Shadow Mountain Government Camp wastewater treatment facility may have been flowing across this sampling station as a density current at the time of sampling.

The samples from Lake Granby showed orthophosphate concentrations two to thirteen times greater at the lake bottom than at the surface, and dissolved oxygen content and pH were consistently lower at the lake bottom.

TABLE IV Summary of Nutrient Concentrations - Grand Lake, Shadow Mountain Lake, Lake Granby

	Inorganic Nitrogen			Orthophosphate			Total Soluble Phosphorus		
	High mgN/l	Low mgN/l	Avg mgN/l	High mgP/l	Low mgP/l	Avg mgP/l	High mgP/l	Low mgP/l	Avg mgP/l
Grand Lake	.12	.06	.082	.0293	.0032	.0084	.109	.013	.043
Shadow Mountain Lake	.62	.07	.145	.1565	.0064	.0526	.254	.013	.065
Lake Granby	.29	.06	.096	.0880	.0032	.0154	.111	.013	.070
All Three Lakes	.62	.06	.107	.1565	.0032	.0255	.254	.013	.059

From these facts, it would appear that organic decomposition in the hypolimnion was converting organic phosphate to soluble polyphosphates and reducing the dissolved oxygen concentration. Since pH generally parallels the dissolved oxygen concentration[3], the hypolimnion may become acidic during the course of the summer; thereby, increasing the rate of hydrolysis of polyphosphates to orthophosphates[10]. Since these physical phenomena were not present in either Grand Lake or Shadow Mountain Lake, it is reasonable to assume that Lake Granby has the highest organic content. This may be the result of either the failure to properly clear the lake bed prior to impoundment or the transportation of the organics deposited in the upper lakes into Lake Granby during the spring runoff period or both.

Although a true thermocline was not found in any of the lakes, both Grand Lake and Lake Granby have two distinct temperature zones and could be classified as thermally stratified (Table V, Figure 3). The use of the terms, epilimnion and hypolimnion, therefore, will be used in discussing the waters above and below that zone of greatest temperature change. In Shadow Mountain Lake, the shallow nature of the reservoir, the mixing due to wind action, and the pumping of colder water from the depths of Lake Granby into Shadow Mountain Lake prevent thermal stratification.

The dissolved oxygen concentrations measured during the first phase of this survey are shown in Table A-1 in the Appendix. Dissolved oxygen profiles were measured at selected stations during the biological phase of the survey as shown in Table V and Figure 3. The dissolved oxygen

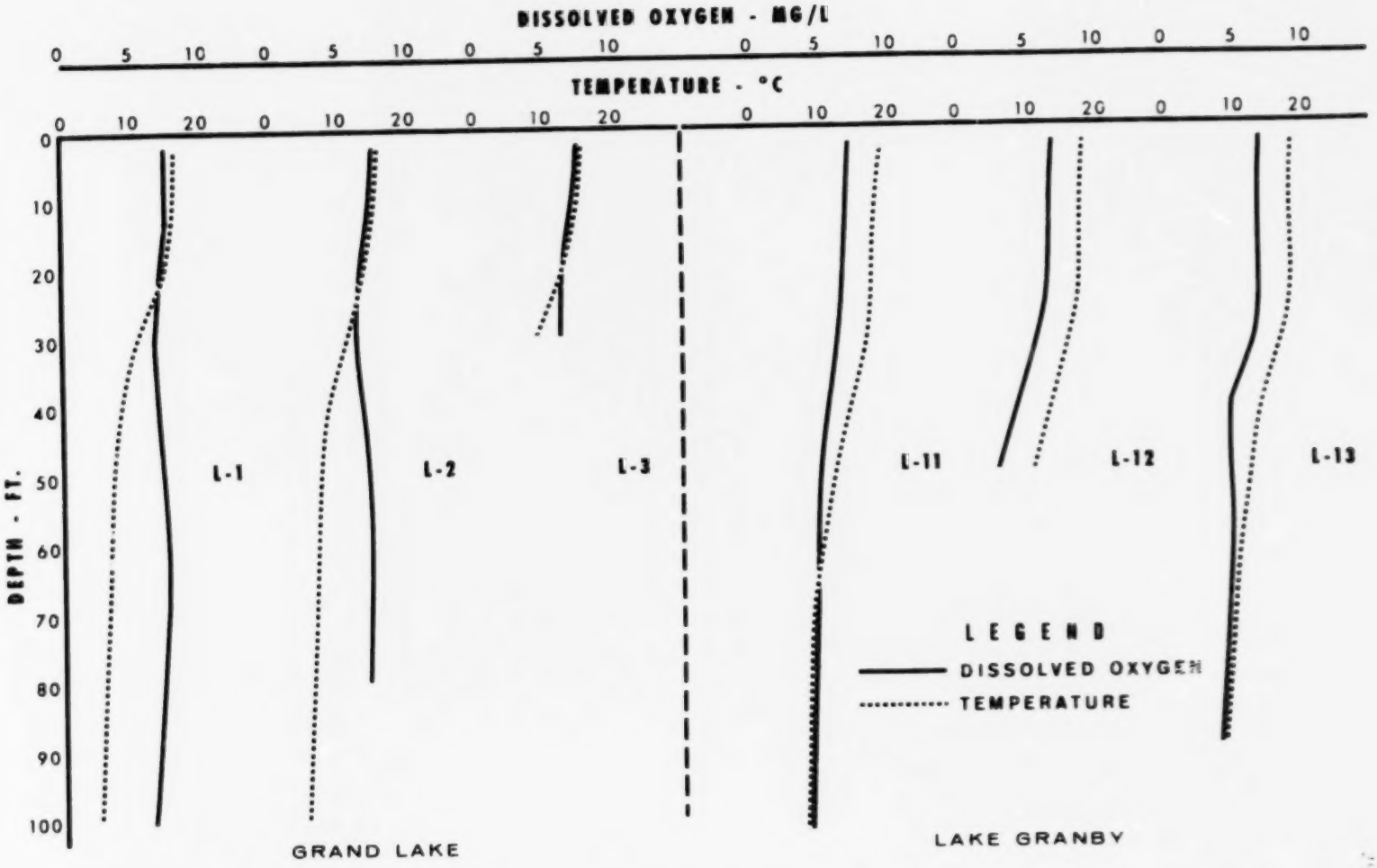

Figure 3. Dissolved Oxygen and Temperature Profiles at Selected Stations

TABLE V Physical Measurements at Selected Lake Stations

Station Number	Date and Time	Sample Depth Ft.[1]	Temperature °C	Dissolved Oxygen mg/l	D.O / D.O. Saturation x100	Secchi Disk Transp. Ft.[1]	Euphotic Zone Ft.[1]
L-1	Sept. 6	2	16.6	7.6	104		
	1530	10	16.6	7.6	104	13.5	36.4
		20	15.0	7.3	97		
		30	10.5	6.6	80		
		40	8.3	7.0	80		
		50	7.8	7.4	84		
		60	7.2	7.6	85		
		70	6.7	7.6	83		
		80	6.0	---	---		
		90	5.5	6.9	74		
		100	5.5	6.4	68		
L-2	Sept. 6	2	16.0	7.6	103		
	1715	10	16.0	7.6	103	12.5	33.5
		20	13.9	6.6	86		
		30	11.6	6.4	79		
		40	8.3	7.0	80		
		60	7.2	7.6	84		
		80	6.1	7.2	78		
		100	5.5	---	---		
L-3	Sept. 6	2	15.5	7.6	102		
	1500	10	15.5	7.6	102		
		20	12.7	6.4	81		
		30	9.4	6.4	81		
L-4	Sept. 5	0	15.0	7.6	101		
	1330	7	15.0	7.3	97	7	Depth of Lake
L-6	Sept. 5	0	15.2	7.2	97		
	1245	16	15.0	7.7	103	7.2	Depth of Lake
L-8	Sept. 5	0	15.0	7.4	99		
	1145	8	14.5	7.2	95	8.0	Depth of Lake

1/ To convert to meters, multiply by .3046.

TABLE V (Continued) Physical Measurements at Selected Lake Stations

Station Number	Date and Time	Sample Depth Ft.[1]	Temperature °C	Dissolved Oxygen mg/l	$\frac{D.O.}{D.O.\ Saturation} \times 100$	Secchi Disk Transp. Ft.[1]	Euphotic Zone Ft.[1]
L-11	Sept. 6	2	19.4	7.0	102		
	1245	10	17.7	7.1	100	12.5	33.5
		20	17.7	---	---		
		30	17.1	6.4	89		
		40	14.4	---	---		
		50	12.1	5.0	62		
		70	8.9	---	---		
		80	8.3	---	---		
		102	8.3	4.0	46		
L-12	Sept. 6	2	18.2	6.8	96		
	1140	10	17.7	6.8	97	14.5	39.1
		25	17.7	6.6	93		
		50	11.0	3.0	36		
L-13	Sept. 6	2	18.2	6.85	97		
	1020	10	17.7	6.8	96	17.0	45.9
		20	18.2	6.75	96		
		30	17.7	6.85	99		
		40	13.5	4.55	58		
		50	12.1	---	---		
		60	10.5	5.0	60		
		90	8.3	3.95	45		

1/ To convert to meters multiply by .3046.

profiles in Grand Lake approximate an orthograde rather than a clinograde pattern with the lowest measured concentration (6.4 mg/l at 5.5°C and 100 feet) equal to 68 percent of saturation. Percentages as high as this obtained from the hypolimnion of a thermally stratified lake late in the summer suggest that the amount of oxidizing organic material is not great and that Grand Lake is only moderately productive.

In Lake Granby, oxygen depletion in the hypolimnion is more severe. Dissolved oxygen concentrations as low as 3.0 mg/l (36 percent saturation) were found at the 50-foot depth of Station L-12. This suggests that, while not extreme, the oxygen pattern is more clinograde than orthograde and that summer-long accumulations of oxygen-demanding organic materials are more concentrated in Lake Granby than in Grand Lake. In the well-mixed waters of the epilimnion, the oxygen content remained close to saturation. The absence of very high values here indicates only a moderate rate of photosynthesis.

In Shadow Mountain Lake, the oxygen concentrations remain uniformly near saturation values throughout the depths showing that the effects of the physical processes of atmospheric reaeration and deaeration override any tendency for oxygen to reach either extreme highs or lows. This is to be expected in such a shallow exposed lake containing moderately productive water.

In Grand Lake and Lake Granby the surface dissolved oxygen values were equal to or greater than 6.0 mg/l, the established dissolved oxygen standard for Class B_1 waters. However, dissolved oxygen concentrations as low as 5.2 mg/l were observed at Station L-5 in Shadow Mountain Lake. Since this station is located on the west side of the lake between two marinas, it is possible that this dissolved oxygen depletion resulted

from the increased recreational use in this area during the Labor Day weekend.

The depth of light penetration into a lake is of biological importance since all rooted, suspended, and floating aquatic plants require light energy for photosynthesis. While light penetration is exceedingly variable in different lakes, it can generally be stated that higher quality water permits greater light penetration.

At the selected lake stations where light penetration was measured (Table V), the euphotic zone, which is calculated from the Secchi Disk transparency measurements, extended through the well mixed upper water into or below the depths of greatest temperature change. Therefore, sufficient light existed throughout the epilimnion for photosynthesis. Shadow Mountain Lake, because of the shallow depths, is entirely within the euphotic zone. The fact that the depth of light penetration was greater than 30 feet in all the lakes is indicative of generally high-quality waters.

Although the blue-green algae, Aphanizomenon flos-aquae, was abundant enough to be discerned visually in the surface water, examination of the Sedgwick-Rafter analyses of water samples (Table VI) indicates that the algae "bloom" conditions found during the October 2, 1967, survey were not present at this time. For this survey, an algae "bloom" is defined as a count of an individual organism exceeding 500/ml (4). The maximum density was observed at Station L-3 in Grand Lake where a count of 527 organisms/ml was recorded at a depth of two feet. Overall, the productivity of the lakes can be considered low since one-half of the

TABLE VI. Sedgwick-Rafter Analyses of Plankton Samples

Location	Station & Depth	Blue-Green Coccoid	Green Coccoid	Green Flagellates	Other Flaggellates	Diatoms	Total Plankton Counts
	L-1, 2'	- - - - - - -	51	17	102	170	340
	L-1,10'	- - - - - - -	34	68	85	34	221
	L-2, 2'	- - - - - - -	68	51	85	85	289
Grand	L-2,10'	- - - - - - -	68	--	---	102	170
Lake	L-2,30'	- - - - - - -	17	51	34	68	170
	L-3, 2'	- - - - - - -	119	85	221	102	527
	L-3,10'	- - - - - - -	170	--	119	119	408
	L-3,30'	- - - - - - -	---	--	34	289	323
Shadow	L-4, 2'	- - - - - - -	17	--	17	102	136
Mountain	L-6, 2'	- - - - - - -	---	--	136	51	187
Reservoir	L-8, 2'	17	---	34	102	119	272
	L-11,2'	17	17	34	---	85	153
	L-11,10'	17	---	34	---	34	85
Granby	L-11,50'	- - - - - - -	---	204	---	17	221
Reservoir	L-13,2'	- - - - - - -	---	85	---	34	119
	L-13,20'	- - - - - - -	34	119	---	17	170

plankton samples had less than 200 organisms/ml, total count. Numerically the most abundant organism in any sample was Dinobryon sp., a yellow-green algae which causes taste and odor problems when present in high concentrations (9).

The net plankton sample analyses (Table VII) provide a different qualitative picture. It is emphasized, however, that net samples are not quantitative because (1) they are biased toward the larger forms, (2) the efficiency increases as the meshes become clogged, and (3) the volume filtered is difficult to control. Notwithstanding these shortcomings, plankton net samples permit the examination of a much larger volume of water than that collected for the Sedgwick-Rafter analysis.

At those stations where net plankton hauls were made, Aphanizomenon flos-aquae was the dominant organism as shown in Table VII. Although the Sedgwick-Rafter analyses revealed low numbers of this organism, calculations based on the amounts of water filtered, the amount of plankton concentrate obtained, and the number of organisms in that concentrate indicate that the densities obtained from both Sedgwick-Rafter and net plankton analyses are comparable. Aphanizomenon flos-aquae was easily seen in the lakes even though present in low numbers because of its habit of forming large aggregates. Similarly, copepods and cladocerans could easily be seen in the lakes though only a few organisms were present. The presence of the blue-green algae Aphanizomenon flos-aquae and Anabaena which are both capable of fixing atmospheric nitrogen (converting molecular nitrogen to ammonia) supports the hypothesis discussed earlier that the phytoplankton are nitrogen limited. In many bodies of water, these forms become abundant during the late summer and early fall months particularly

TABLE VII Net Plankton Sample Analyses

Genera Species	Grand Lake L-3 Oblique Hand Tow	Shadow Mountain Lake L-4 Oblique Hand Tow	Shadow Mountain Lake L-6 Vert. Haul From 20' Deep	Shadow Mountain Lake L-8 Surface Tow	Lake Granby L-12 Vert. Haul From 25' Deep	Lake Granby L-13 Vert. Haul From 17' Deep
Rotifers						
Asplanchia sp.	3	19	26	10	56	59
Kellicottia sp.	1		1		1	
Synchaeta sp.			6		106	72
Cladocerans						
Bosmina sp.	48	3	3	55		
Daphnia spp.	121	88	88	322	104	31
Copepods						
Cyclops sp.	11	6	28	13	13	20
Diaptomus spp.	18	8	6	78	127	47
Water Mite			1			
Blue Greens						
Aphanizomenan flos-aquae	14,586	19,320	9,905	74,690	201,460	167,160
Oscillatoria sp.			35			
Anabaena sp.	3	5		70		
Greens						
Volvox sp.	101	22	8	95		8
Scenedesmus sp.			35			
Dictyosphaerium sp.			17			
Oedogonium sp.	2	70				
Pandorina sp.	85					
Pediastrum sp.		1				
Carteria sp.				70		
Closterium sp.				70		
Unknown coccoid form				280		
Other						
Dinobryan sp.		210	70	350		

TABLE VII (Continued) Net Plankton Sample Analyses

Genera Species	Grand Lake L-3 Oblique Hand Tow	Shadow Mountain Lake L-4 Oblique Hand Tow	Shadow Mountain Lake L-6 Vert. Haul From 20' Deep	Shadow Mountain Lake L-8 Surface Tow	Lake Granby L-12 Vert. Haul From 25' Deep	Lake Granby L-13 Vert. Haul From 17' Deep
Diatoms						
Navicula sp.		70	70			
Fragilaria sp.		1,610	70	9,380		
Asterionella sp.		210	105	910		
Cymbella sp.			35			
Cyclotella sp.			105			
Melosira spp.		3,780	490	350		
Fragilaria Crotonensis		3,990				
Cyclotella Bodanica				8,120		
Nitzschia sp.		70				
Tabellaria sp.		560				
Stephanodiscus sp.		210				
Totals	15,065	30,252	11,087	94,863	201,867	167,397

if high phosphorus to nitrogen ratios prevail. Therefore, reduction of the phosphorus concentration in the lake is necessary to prevent "blooms" by the nitrogen-fixing blue-green algae. Since the natural removal of phosphorus by outflows and combination with consolidated bottom sediments is a slow process, a reduction in the phosphorus inflows to the lakes is the logical control measure.

While bottom vegetation was not sampled in any of the lakes, it was observed in relative abundance in Shadow Mountain Lake. The bottom growth was particularly thick along the west shoreline of Shadow Mountain Lake. This same area was reported to have light to moderate growth during the October 2, 1967, survey.

EFFECTS OF NATURAL INFLOWS UPON THE WATER QUALITY IN THE LAKES

The chemical and physical data for all tributary stations are contained in Table VIII. The natural runoff into the lakes (Station I-1 through I-11) had a flow-weighted average inorganic nitrogen concentration of 0.07 mgN/1, orthophosphate concentration of 0.007 mgP/1, and total soluble phosphorus concentration of 0.064 mgP/1. Comparing this with the criteria established earlier, it is apparent that the total soluble phosphorus concentrations in the natural inflows is greater than the upper limit of 0.05 mgP/1 suggested for low flow conditions while the orthophosphate concentration is less than the suggested limit of 0.010 mgP/1. At the time of this survey, the tributary inflow approached low flow conditions which is generally associated with higher mineral concentrations. Therefore, the average annual natural orthophosphate and total soluble phosphorus inputs from the natural inflows are believed to be less than 0.010 mgP/1 and 0.050 mgP/1 respectively, but a short-term water quality surveillance program to collect

TABLE VIII Flow and Nutrient Concentrations Measured at Tributary Stations

Station Number	Date & Time Sampled	Gage Ht/Flow Cfs.[1/]	Nitrogen			Phosphates	
			NO_3- mgN/l	NH_3- mgN/l	Inorganic mgN/l	Ortho mgP/l	Total-Sol mgP/l
I-1	Aug. 28 0840	4.00 38.80	.05	.02	.07	.003	.062
I-2	Aug. 28 0905	4.17 4.50	.05	.02	.07	.003	.059
I-3	Aug. 28 1015	0.97 1.70	.05	.01	.06	.003	.082
I-4	Aug. 28 1000	3.25 1.80	.05	.02	.07	.003	.039
I-5	Aug. 28 1600	0.78 17.00	.05	.01	.06	.003	.062
I-6	Aug. 28 1615	7.69 26.70	.05	.02	.07	.003	.065
I-7	Aug. 28 1640	0.45 2.20	.05	.04	.09	.023	.072
I-9	Aug. 28 1335	3.49 28.00	.05	.01	.06	.006	.055
I-10	Aug. 28 1250	4.60 0.10	.05	.03	.08	.110	.166
I-11	Aug. 28 1235	0.62 3.60	.05	.02	.07	.091	.144
Flow Weighted Average I-1 through I-11			.05	.02	.07	.007	.064

1/ To convert to M^3/Sec. multiply by .02832.

flow and quality data during all flow cycles should be conducted to affirm this assumption.

EFFECT OF WASTEWATER DISCHARGES UPON NUTRIENT LEVELS IN THE LAKES

Two sources of treated wastewater enter the lakes studied. The major sources are the Grand Lake and the Shadow Mountain Government Camp wastewater treatment facilities which serve approximately 4,000 people during the summer months and about 450 people the remainder of the year. The residences and businesses which use septic tank and subsurface disposal fields for wastewater treatment and disposal constitute the other sources. According to personnel of the Colorado State Health Department (5), there are approximately 300 residences and businesses served by individual systems. On a typical summer weekend, these individual systems probably receive the wastes of 1,500 or more people.

The quality of the effluent from the Grand Lake wastewater treatment facility is believed to be similar to the quality of the effluents from the Shadow Mountain Government Camp system and the individual systems and representative of the nutrient inflows from wastewater. Therefore, the effects of wastewater on the lakes were evaluated by sampling the Grand Lake wastewater treatment facility effluent. The results of the chemical analyses in Table IX show that the concentrations of ammonia, orthophosphates and total soluble phosphates averaged 13.38 mgN/l, 5.21 mgP/l and 6.14 mgP/l respectively, and are two to three orders of magnitude greater than the concentrations determined in natural runoff.

A more realistic view of the impact of domestic wastewater nutrients on the lakes can be presented by conversion of the nutrient concentrations from mg/l to lbs/day as shown in Table X. Analysis of this data shows

TABLE IX Flow and Nutrient Concentrations
Measured in the Grand Lake Wastewater Treatment Facility Outfall, Station I-16

Date and Time	Flow gpm[1/]	NITROGEN			PHOSPHATES	
		Nitrate mgN/l	Ammonia mgN/l	Inorganic mgN/l	Ortho mgP/l	Total Soluble mgP/l
Aug. 28 1030	30	.05	9.7	9.75	6.20	7.18
Aug. 29 1310	202	.05	11.0	11.05	4.57	5.87
Aug. 30 1515	150	.05	13.0	13.05	4.57	5.55
Aug. 31 1630	202	.05	16.0	16.05	5.55	6.85
Sept. 1 1325	202	.05	18.0	18.05	5.55	6.20
Sept. 2 1625	175	.09	8.7	8.79	5.55	5.87
Flow Weighted AVERAGE	160	.06	13.38	13.43	5.21	6.14

1/ To convert to M^3/Sec. multiply by $.63 \times 10^{-4}$.

TABLE X Measured Nutrient Input (Lbs/Day) to the Lakes From Natural and Wastewater Flows

Sta. No.	Flow AcFt/Day[1]	NITROGEN			PHOSPHATES	
		Nitrate lbsN/Day[2]	Ammonia lbsN/Day[2]	Inorganic lbsN/Day[2]	Ortho lbsP/Day[2]	Total Soluble lbsP/day[2]
I-1	77.0	10.5	4.2	14.7	0.69	12.99
I-2	8.9	1.2	0.5	1.7	0.08	1.43
I-3	3.4	0.5	0.1	0.6	0.03	0.76
I-4	3.6	0.5	0.2	0.7	0.03	0.38
I-5	33.7	4.6	0.9	5.5	0.30	5.68
I-6	53.0	7.2	2.9	10.1	0.48	9.37
I-7	4.4	0.6	0.5	1.1	0.28	0.86
I-9	55.5	7.5	1.5	9.0	0.98	8.30
I-10	0.2	0.3	0.2	0.5	0.06	0.09
I-11	7.1	1.0	0.4	1.4	1.76	2.78
		33.9	11.4	45.3	4.69	42.64
		WASTEWATER FLOWS				
I-16[3]	0.7	0.1	25.5	25.6	9.92	11.69

1/ To convert to M^3/Sec. multiply by .01428.
2/ To convert to Kg/Day multiply by .4536.
3/ Flow-Weighted Average.

that the Grand Lake wastewater treatment facility effluent, while contributing only 0.28 percent of the total inflow, contributed 36 percent of the inorganic nitrogen, 68 percent of the orthophosphates, and 21.5 percent of the total soluble phosphates as compared to the natural runoff contributions of 97.72 percent of the flow, 64 percent of the inorganic nitrogen, 32 percent of the orthophosphates, and 78.5 percent of the total soluble phosphates.

Phosphorus is the element most often limiting to aquatic plant growth. However, when present in abundance in conjunction with other environmental conditions, phosphorus can stimulate algae growths that produce nuisance tastes and odors, fish kills and otherwise impair water uses. Unlike nitrogen, phosphorus cannot be fixed from the atmosphere by plants and is added to the lakes by natural runoff or wastewater discharges (7). For biological growth, the orthophosphate ion is the most readily available source of phosphorus (8). As shown above, the Grand Lake wastewater treatment facility contributed 68 percent of the orthophosphates entering the lakes during the time of this survey. Considering this and the additional quantity and quality of wastewater entering the lakes from other sources, the evidence is that wastewater, the major contributor of orthophosphates, is the cause of nutrient pollution of these lakes.

The natural runoff provided 99.7 percent of the inflow with an orthophosphate concentration of 0.007 mgP/l. Therefore, to restrict the flow-weighted average orthophosphate concentration entering the lake to 0.010 mgP/l, the suggested maximum, the orthophosphate concentration in wastewaters discharged to the lake cannot exceed 1.054 mgP/l. Since the measured orthophosphate concentration in the Grand Lake wastewater treatment facility

effluent was 5.21 mgP/l, an additional 80 percent reduction in orthophosphate is required. This can only be accomplished by advanced waste treatment methods.

Beyond nutrient inputs, it has been shown that organic matter is also an important factor affecting the growth of algae, although the specific amount of organic matter necessary to sustain growth has not been quantified (8). Hinman (2) presents data showing that the Grand Lake wastewater treatment facility only achieved a 45 percent suspended solids reduction during August 1969, and the sludge accumulations noticed during the October 2, 1967, survey were also observed by Federal Water Pollution Control Administration personnel during this survey. Therefore, the organic matter necessary for algae growth is probably present in the lakes and is contributed primarily by wastewater inflows.

In addition to phosphorus removal, an increase in the removal of organic matter from wastewaters is also necessary to prevent water quality degradation. However, the contribution of organic matter by natural runoff is unknown and must be evaluated as part of water pollution control programs for the lakes.

No information is available regarding the quality of spring runoff, the effects of ice cover on water quality, etc. Development of a comprehensive plan for water quality control in the three lakes area will require that these factors be evaluated.

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APPENDIX A

PHYSICAL AND CHEMICAL DATA FOR LAKE STATIONS

Table A-1 Physical-Chemical Data for Lake Stations

Station Number	Date & Time Sampled	Sample Depth Feet	Temperature °C	pH	Specific Cond. µmhos	D. O. mg/l	NITROGEN NO_3- mg/l as N	NITROGEN NH_3 mg/l as N	NITROGEN Organic mg/l as N	NITROGEN Total Kjeldahl mg/l as N	PHOSPHATES Ortho mg/l PO_4	PHOSPHATES Total mg/l PO_4	PHOSPHATES Soluble mg/l P
L-1	8/28/69	0.0	16.0	7.4	--	8.1	≤.05	.01	.15	.16	.02	.11	.036
	1015&1000	60.0	17.0	7.6	--	8.0	≤.05	.03	.12	.15	.01	.19	.062
	8/30/69	0.0	15.5	7.5	50	7.9	≤.05	.02	.18	.20	.02	.06	.020
	1120	120.0	8.5	7.3	<50	6.9	.09	.01	.22	.23	.04	.04	.013
	9/1/69	0.0	14.5	7.6	<50	7.1	≤.05	.02	.25	.27	.02	.15	.049
	0945	120.0	9.0	7.6	<50	7.3	≤.05	.05	.31	.36	.01	.12	.031
	9/3/69	0.0	15.5	7.4	<50	7.0	≤.05	.02	.18	.20	.02	.06	.020
	1005	135	11.5	6.9	<50	7.1	.09	.96	.20	.26	.04	.07	.023
L-2	8/28/69	0.0	17.0	7.6	--	8.0	≤.05	.03	.19	.22	.01	.23	.075
	1045	130.0	9.0	6.8	--	6.5	.08	.02	.12	.14	.03	.21	.068
	8/30/69	0.0	15.0	7.3	< 50	8.0	≤.05	.03	.18	.21	.01	.16	.052
	1135	70.0	8.5	7.1	< 50	7.6	.10	.02	.14	.16	.03	.04	.013
	9/1/69	0.0	15.5	7.6	< 50	6.8	≤.05	.02	.21	.23	.01	.06	.020
	1005	80.0	7.5	7.3	< 50	7.6	.06	.03	.18	.12	.01	.14	.046
	9/3/69	0.0	15.5	7.5	< 50	7.5	≤.05	.03	.16	.19	.02	.06	.020
	1025	70.0	13.0	7.3	< 50	7.5	≤.05	.03	.20	.23	.01	.06	.020
L-3	8/28/69	0.0	17.0	---	--	8.0	≤.05	.02	.15	.17	.02	.22	.072
	1115	30.0	17.0	7.1	--	8.0	≤.05	.02	.16	.18	.02	.33	.108
	8/30/69	0.0	15.0	8.3	< 50	8.0	≤.05	.01	.13	.14	.01	.11	.035
	1110	40.0	12.0	7.4	< 50	7.2	≤.05	.04	.21	.25	.06	.21	.068
	9/1/69	0.0	15.0	7.3	< 50	6.9	≤.05	.02	.20	.22	.01	.12	.039
	1015	40.0	10.5	6.9	< 50	7.0	≤.05	.02	.15	.17	.08	.20	.065
	9/3/69	0.0	15.5	7.0	<50	7.0	≤.05	.01	.14	.15	.03	.06	.020
	0955	40.0	10.5	7.2	<50	7.1	≤.05	.02	.14	.16	.09	.13	.042
L-4	8/28-0930	2.5	13.0	7.2	--	7.8	≤.05	.02	.18	.20	.03	.28	.091
	8/29-1250	2.5	14.5	7.8	63	7.9	≤.05	.03	.27	.30	.05	.20	.065
	8/30-1150	5.0	14.0	7.2	63	8.4	≤.05	.02	.15	.17	.04	.08	.026
	8/31-1535	5.0	15.0	8.5	--	7.1	≤.05	.05	.21	.26	.04	.08	.026
	9/1-1135	5.0	14.0	7.5	60	5.2	≤.05	.07	.15	.22	.04	.15	.049
	9/3-0915	4.0	15.0	7.4	<50	6.7	≤.05	.01	.12	.13	.04	.08	.026

Table A-1(Continued) Physical-Chemical Data for Lake Stations

Station Number	Date & Time Sampled	Sample Depth Feet	Temperature °C	pH	Specific Cond. µmhos	D. O. mg/l	NITROGEN NO_3- mg/l as N	NITROGEN NH_3 mg/l as N	NITROGEN Organic mg/l as N	NITROGEN Total Kjeldahl mg/l as N	PHOSPHATES Ortho mg/l PO_4	PHOSPHATES Total mg/l PO_4	PHOSPHATES Soluble mg/l P
L-5	8/29/69	0.0	14.0	7.5	63	7.8	≤.05	.03	.43	.46	.02	.06	.020
	1300	20.0	14.0	7.1	62	6.0	≤.05	.19	.29	.48	.02	.10	.033
	9/1-1115	6-12	13.0	6.8	60	5.6	≤.05	.05	.35	.40	.02	.05	.016
	9/3-0930	5-10	13.5	7.1	<50	5.2	≤.05	.02	.13	.15	.03	.06	.020
L-6	8/29/69	0.0	15.0	7.5	63	7.8	≤.05	.02	.20	.22	.02	.04	.013
	1240	20.0	13.0	7.4	60	6.3	≤.05	.05	.32	.37	.03	.06	.020
	9/2	0.0	15.0	7.3	60	7.2	≤.05	.02	.23	.25	.02	.03	.010
	1345	20.0	12.0	7.1	63	5.8	≤.05	.03	.14	.17	.11	.17	.055
L-7	8/29-1225	7.5-15	15.0	7.5	52	8.0	≤.05	.03	.24	.27	.39	.43	.140
	9/2/69	0.0	16.0	7.7	60	6.8	≤.05	.02	.15	.17	.03	.06	.020
	1330	20.0	12.0	7.0	63	5.6	≤.05	.02	.17	.19	.09	.10	.033
L-8	8/29-1340	2.5-5	17.0	7.7	70	8.3	≤.05	.57	.39	.96	.48	.78	.254
	8/30-1500	2.5-5	17.5	8.0	<50	7.5	≤.05	.06	.38	.44	.19	.25	.082
L-9	8/29/69	0.0	19.0	7.5	55	7.6	≤.05	<.01	.10	.11	.02	.22	.072
	1130	36.0	14.0	7.3	50	6.4	≤.05	.10	.14	.24	.10	.31	.101
	9/2/69	0.0	18.5	7.6	55	6.6	≤.05	.01	.11	.12	.02	.08	.026
	1135	34.0	14.5	7.0	60	4.8	≤.05	.03	.18	.21	.04	.08	.026
L-10	8/29/69	0.0	18.0	7.9	55	7.8	≤.05	<.01	.15	.16	.01	.26	.085
	1110	50.0	11.0	7.1	55	5.1	.11	<.01	.15	.16	.08	.27	.088
	9/2/69	0.0	18.0	7.3	60	6.6	≤.05	.02	.18	.20	.02	.04	.013
	1115	66.0	11.0	7.0	55	4.1	.13	.02	.23	.25	.14	.14	.046
L-11	8/29/69	0.0	18.0	7.1	55	7.5	≤.05	.01	.15	.16	.01	.15	.099
	1100	76.0	10.0	6.5	60	5.2	.14	.03	.17	.20	.05	.33	.108
	9/2/69	0.0	18.0	7.7	60	7.5	≤.05	.01	.13	.14	.02	.04	.013
	1100	110.0	11.0	7.2	55	4.1	≤.05	.24	.28	.52	.27	.28	.091

Table A-1 (Continued) Physical-Chemical Data for Lake Stations

Station Number	Date & Time Sampled	Sample Depth Feet	Temperature °C	pH	Specific Cond. umhos	D. O. mg/l	NITROGEN NO_3- mg/l as N	NITROGEN NH_3 mg/l as N	NITROGEN Organic mg/l as N	NITROGEN Total Kjeldahl mg/l as N	PHOSPHATES Ortho mg/l PO_4	PHOSPHATES Total mg/l PO_4	PHOSPHATES Soluble mg/l P
L-12	8/29/69	0.0	18.0	8.5	55	7.2	≤.05	.02	.16	.18	.01	.33	.107
	0930	40.0	12.0	6.8	60	4.4	.08	.03	.17	.20	.07	.32	.104
L-13	8/29/69	0.0	19.0	6.9	55	7.6	≤.05	.02	.22	.24	.01	.18	.059
	1025	34.0	13.0	6.3	55	5.0	≤.05	.03	.14	.17	.04	.34	.111
L-14	8/29-1010	7.5-15	18.0	7.6	55	7.1	≤.05	.03	.16	.19	.02	.24	.078
	9/2-1020	5-10	17.0	7.1	52	6.1	≤.05	.03	.18	.21	.03	.06	.020
L-15	8/31-1510	0.0	17.0	9.7	≯250	12.6	≤.05	.02	.19	.21	.04	.06	.070

A P P E N D I X B

WATER QUALITY STANDARDS FOR COLORADO

COLORADO DEPARTMENT OF HEALTH
Water Pollution Control Commission
4210 East 11th Avenue
Denver, Colorado 80220
Adopted May 15, 1968

WATER QUALITY STANDARDS FOR COLORADO

The Second Session of the Forty-Fifth General Assembly of the State of Colorado passed Water Pollution Control Legislation for the State of Colorado as set out in Chapter 44, Session Laws 1966. In adopting this legislation, the following legislative declaration was made:

> "Whereas the pollution of the waters of this state constitutes a menace to public health and welfare, creates public nuisances, is harmful to wildlife, fish and other aquatic life, and impairs domestic, agricultural, industrial, recreational, and other beneficial uses of water; and whereas the problem of water pollution of this state is closely related to the problem of water pollution in adjoining states; and whereas it is the public policy of this state to conserve the waters of the state and to protect, maintain, and improve the quality thereof for public water supplies, for the propagation of wildlife, fish and other aquatic life, and for domestic, agricultural, industrial, recreational, and other beneficial uses, and to provide that no wastes be discharged into any waters of the state without first being given the degree of treatment necessary to protect the beneficial uses of such water, it is hereby declared that the prevention, abatement, and control of the pollution of the waters of this state are affected with a public interest, and the provisions of this act are enacted in the exercise of the police powers of this state for the purpose of protecting the health, peace, and safety, and general welfare of the people of this state."

These standards are the foundation for the classification of the waters of the State of Colorado.

Standards are subject to revision as technical data, surveillance programs, and technological advances make such revisions desirable.

For purposes of enforcement of these standards, sampling will be done at a point where these standards can be evaluated.

For purposes of enforcement of water classification standards, sampling of the waters will be done at any point, except for areas immediately adjacent to outfalls and except as may be noted in the text of the standards. In such areas, cognizance will be given to the opportunity for admixture of waste effluents with receiving water.

Tests or analytical procedures to determine compliance with standards will, insofar as practicable and applicable, be made in accordance with the methods given in the latest edition of "Standard Methods For The Examination Of Water And Waste Water" published by the American Public Health Association, or in accordance with tests or analytical procedures that have been found to be equal or more applicable and satisfactory and accepted and approved by the Commission.

In areas where a body of water is classified for more than one use, the standards applicable to each use shall apply and in case of a conflict, the more restrictive standards snall prevail in each instance.

Where and when additional waters become available, hearings will be held on the possible classification or reclassification of such waters for further enhancement. The quality of water will be maintained as high as possible and in no case shall stream standards be violated.

It is expected that the present uses of the waters of Colorado will continue but if other uses develop, streams may be classified or reclassified after public hearings.

I. BASIC STANDARDS APPLICABLE TO ALL WATERS:

A. All wastes capable of treatment or control prior to discharge into any waters of the state, shall receive secondary treatment with disinfection or its industrial waste equivalent, as determined by the State Water Pollution Control Commission. Lesser degrees of treatment or control may be permitted only where it can be demonstrated that the standards applicable to the classified use of the water can be attained. Greater degrees of treatment or control will be required where it can be demonstrated that it is necessary to comply with the standards applicable to the classified use of the water.

B. Free from substances attributable to municipal, domestic, or industrial wastes, or other controllable sources that will either settle to form unsightly, putrescent, or odorous bottom deposits, or will interfere with the classified use of the water.

C. Free from unsighly floating debris, oil, grease, scum, and other floating material attributable to municipal, domestic, or industrial wastes, or other controllable sources.

D. Free from materials attributable to municipal, domestic, or industrial wastes, or other controllable sources that will produce odor in the water or produce an appreciable change in the existing color, taste, turbidity or other conditions that interfere with the classified use of the water.

E. Free from high temperatures, biocides, toxic, or other deleterious substances attributable to municipal, domestic, or industrial wastes, or other controllable sources in levels, concentrations, or combinations sufficient to be harmful to human or animal life.

F. Radioactive materials attributable to municipal, industrial or other controllable sources will be minimum concentrations that are physically and economically feasible to achieve. In no case shall such materials in the stream exceed the limits established in the current edition of the U.S. Public Health Service Drinking Water Standards or the limits approved by the Federal Radiation Council, or, in the absence of any limits specified by the U.S. Public Health Service or the Federal Radiation Council, 1/30 of the 168-hour-week values for other radioactive substances specified in the National Bureau of Standards Handbook 69.

II. ADDITIONAL WATER QUALITY STANDARDS FOR BODIES OF WATER THAT HAVE BEEN CLASSIFIED FOR ANY OF THE FOLLOWING USES:

CLASS A.

The following standards shall apply to water withdrawn for treatment as a potable supply:

1. Bacteria: The annual average number of coliform bacteria at any sampling station shall not exceed the historical average by more than 20% and in no case shall the monthly average of the number of coliform bacteria exceed 5,000 per 100 milliliter (either MPN or MF count). All averages shall be computed logarithmically.

2. Dissolved Oxygen: Dissolved oxygen shall not be less than 4 milligrams per liter.

3. pH: The pH shall be maintained between 6.0 and 9.0.

4. Taste and Odor: Free from materials attributable to municipal, domestic, or industrial wastes, or other controllable sources that will produce taste or odor in the water.

5. Dissolved Solids: Total dissolved solids, annual volume weighted average, should be less than 500 milligrams per liter.

6. Selected Chemical Constituents: The follcwing substances shall not be present in such amounts as to exceed the specified concentrations in a potable water supply according to the mandatory requirements of the latest edition of the U.S. Public Health Service Drinking Water Standards:

Substance	Concentration - mg/l
Arsenic	0.05
Barium	1.00
Cadmium	0.01
Chromium (Hexavalent)	0.05
Cyanide	0.20
Lead	0.05
Selenium	0.01
Silver	0.05

CLASS B.

1. The following standards shall apply to waters classified for fish and wildlife (Cold Water Fishery):

   a. Dissolved Oxygen: In cold water fisheries, the dissolved oxygen content shall in no case go below 6 milligrams per liter.

   b. pH: pH shall be maintained between 6.5 and 8.5. No controllable pH change will be permitted which will interfere with fish and aquatic life.

   c. Turbidity: No turbidity shall exist in concentrations that will impair natural and developed fisheries.

   d. Temperature: In cold water fisheries the temperatures shall not exceed 70° F. No controllable temperature change will be permitted which will interfere with the spawning and other aspects of fish life.

   e. Toxic Material: Free from biocides, toxic, or other deleterious substances attributable to municipal, domestic, or industrial wastes, or other controllable sources in levels, concentrations, or combinations sufficient to be harmful to aquatic life.

   f. Other Material: Free from materials attributable to municipal, domestic, or industrial wastes, or other controllable sources that will produce off-flavor in the flesh of fish.

2. The following standards shall apply to waters classified for fish and wildlife (Warm Water Fishery):

   a. Dissolved Oxygen: In warm water fisheries, dissolved oxygen content shall in no case go below 5 milligrams per liter.

   b. pH: pH shall be maintained between 6.5 and 8.5. No controllable pH change will be permitted which will interfere with fish and aquatic life.

   c. Turbidity: No turbidity shall exist in concentrations that will impair natural and developed fisheries.

   d. Temperature: In warm water fisheries the temperatures shall not exceed 90° F. No controllable temperature change will be permitted which will interfere with spawning and other aspects of fish life.

   e. Toxic Material: Free from biocides, toxic, or other deleterious substances attributable to municipal, domestic, or industrial wastes, or other controllable sources in levels, concentrations, or combinations sufficient to be harmful to aquatic life.

   f. Other Material: Free from materials attributable to municipal, domestic, or industrial wastes, or other controllable sources that will produce off-flavor in the flesh of fish.

CLASS B - continued

3. The following standards shall apply to recreational waters classified for body contact sports such as, but not limited to, swimming and water skiing:

   a. Bacteria: Total coliform bacteria shall not exceed 1,000 per 100 milliliters as a monthly average (either MPN or MF count); nor exceed this number in more than 20% of the samples examined during any month; nor exceed 2,400 per 100 milliliters in a single sample. In addition, the fecal coliform count shall not exceed 100 per 100 milliliters and the fecal streptococcus count shall not exceed 20 per 100 milliliters, both of these limits to be an average of five (5) consecutive samples within a month.

   b. pH: pH shall be maintained between 6.5 and 8.5.

CLASS C:

The following standards shall apply to waters classified for industrial uses:

1. Dissolved Oxygen: Dissolved oxygen content shall not go below 3 milligrams per liter.

2. pH: pH shall be maintained between 5.0 and 9.0.

3. Turbidity: No turbidity shall exist in concentrations that will interfere with established levels of treatment.

4. Temperature: The temperature shall not exceed 93° F.

CLASS D:

1. The following standards shall apply to waters classified for irrigation:

   a. Total Dissolved Solids (Salt)Concentration:

      A time-weighted monthly mean at a monitoring station which exceeds the time-weighted monthly mean for a base period established by the Commission by more than two standard deviations shall be subject to review by the Commission.

   b. Sodium Adsorption Ratio:

      A time-weighted monthly mean at a monitoring station which exceeds the time-weighted monthly mean for a base period established by the Commission by more than two standard deviations shall be subject to review by the Commission.

CLASS D - continued

c. Toxic Material:

Free from biocides, toxic, or other deleterious substances attributable to municpal, domestic, industrial wastes, or other controllable sources in concentrations or combinations which are harmful to crop life.

2. The following standards shall apply to waters classified for livestock watering:

a. Soluble Salts: The soluble salts shall not exceed 3,000 milligrams per liter.

Betty M. Chronic

Betty M. Chronic, Secretary
Colorado Water Pollution Control Commission

R. T. Eckles

Richard T. Eckles, Chairman
Colorado Water Pollution Control Commission

APPENDIX C

GLOSSARY

GLOSSARY

ALGAE BLOOM - A concentration of phytoplankton exceeding 500 organisms/ml.

BENTHIC REGION - The bottom of lakes and streams; the substratum that supports the bottom dwelling plants and animals.

CLINOGRADE - A distribution of dissolved oxygen in the hypolimnion which decreases with depth - approaching zero near the lake bottom.

EPILIMNION - That upper layer of a body of water in which the water temperature is virtually uniform.

EUPHOTIC ZONE - The surface layers of a lake in which light provides the energy for organic production from mineral substances.

EUTROPHIC WATERS - Waters with a good supply of nutrients; they may support rich organic production, such as algal blooms.

EUTROPHICATION - The intentional or unintentional enrichment of water.

HYDROLYSIS - A chemical reaction in which a compound reacts with the ions of water to form a weak acid, a weak base, or both.

HYPOLIMNION - The region of a body of water which extends from the thermocline to the bottom of the lake and has a nearly uniform temperature.

MESOTROPHIC - Waters with a moderate supply of nutrients; they will support organic production and will occasionally support algal blooms.

OLIGOTROPHIC WATERS - Waters with a small supply of nutrients; hence, they support little organic production.

ORTHOGRADE - A nearly uniform distribution of oxygen in the hypolimnion of a lake.

PHOTOSYNTHESIS - The process by which living plant cells, in the presence of light, convert organic and inorganic matter to cell material.

PHYTOPLANKTON - Plant microorganisms, such as certain algae, living unattached in the water.

PLANKTON - Organisms of relatively small size, mostly microscopic, that either have relatively small powers of locomotion or drift in the water subject to the action of waves and currents.

SECCHI DISC - A circular metal plate, 20 cm in diameter, the upper surface of which is divided into four equal quadrants and so painted that two quadrants directly opposite each other are black and the intervening ones white.

THERMOCLINE - The layer in a body of water in which the drop in temperature equals or exceeds one degree centrigrade for each meter or approximately three feet of water depth.